SOLAR POWERED HF AMATEUR/MARS STATION
6 JUN 2018
AAR6UK

Solar panels require no fuel other than sunlight. They produce no emissions, no fumes and have no rotating parts. Other than an occasional wipe down to remove dust, they are virtually maintenance-free.
Solar panels are used with batteries to store electrical energy produced during the day for use at night or when the sun is shaded by clouds. This combination of solar panels and batteries allows 24-hour operation with only occasional help from a generator when solar conditions are less than optimal.

SOLAR POWER COMPONENTS

The selection of solar power components to provide 100% of the required power to sustain An Amateur/MARS station requires careful design. The steps in the design include the following:

1. Calculation of the total required solar power based on station power requirements including operating time per day.
2. Evaluation of the average daily insolation.
3. Selection of the Solar Panels.
4. Selection of the solar charge controller.
5. Selection of storage batteries.

Available Solar Power

The most productive hours of sunshine for solar electric generation are from 9 AM to 3 PM. The morning and later afternoon sun is less intense and the angle of the sun is not optimum for the solar panels. The average sun hours varies with geographic location as shown in Figure 1. The zone definitions are shown in Table 1.

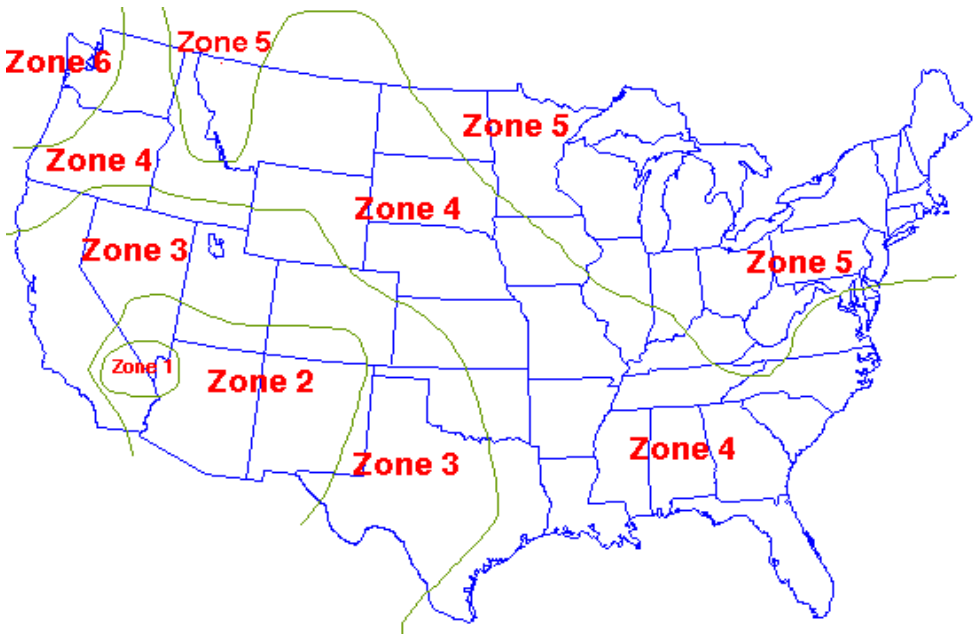

Figure 1: Solar Insolation Map

Table 1: Zone Definitions for Figure 2

Zone 1	**6 hours**
Zone 2	**5.5 hours**
Zone 3	**5 hours**
Zone 4	**4.5 hours**
Zone 5	**4.2 hours**
Zone 6	**3.5 hours**

A web calculator for solar insolation by city can be found at:
http://www.wholesalesolar.com/Information-SolarFolder/SunHoursUSMap.html

For central Texas, the average solar insolation is 5 hours per day or 5000 watts/m^2 per day. For maximum efficiency, the solar array must be located such that no shade will fall on it during its maximum insolation period. Further, the elevation and azimuth must be adjusted to maximize solar ray angle. The solar array should be pointed due south (true) and tilted from horizontal as follows:
Winter – Latitude x .89 + 24º
Spring/Fall – Latitude x .92 – 2.3º
Summer – Latitude x .92 - 24.3º
An active azimuth/elevation sun tracker would provide the best solution. There are claims that an active azimuth/elevation sun tracker could increase the power output per year by as much as 70% in south Texas.

Solar Panel Selection

Types of Solar Cells

Monocrystalline Cell – This cell was the most popular and has been produced for the longest period of time. It consists of a single grown silicon crystal that is sliced into thin wafers, processed chemically, and finally covered with electrodes to collect the electric charge. They are typically blue or black and have shiny appearance. Typical efficiencies are of 18% - 22%.
Polycrystalline or Multicrystalline Cell – This cell type is now the most popular. It is made by slicing wafers from cast square silicon ingots. This cheaper grade of silicon results in a cell with less efficiency but cheaper in cost. These cells appear frosted. Typical efficiencies are 12% - 16%.
Amorphous or Thin-Film Cell – These cells are usually created by applying doped silicon or other photo-voltaic material to the back of a plate of glass or a flexible insulator. Efficiencies of 6% to 10% are commercially available.

Solar Panel Design

Solar cells are connected in parallel to increase current, and in series to increase the voltage output. When cells are connected together they form solar panels. Solar panels can then be connected together to form solar arrays. Arrays can be connected in series or parallel to increase current or voltage output.
A single silicon solar cell, regardless of the type, produces about 0.5 VDC. A 12 volt solar panel consists of 36 cells and produces 18 VDC output. The amount of current produced by a specific type of solar cell is a function of its active surface area, efficiency and the intensity of the solar radiation or insolation. Standard Test Condition (STC) insolation is 1000 W/m^2 at 25 ºC. Solar Panels will have a maximum power output that is the product of its output voltage and current at STC. Drawing more current from a solar panel than its maximum rated current will produce a rapid drop in output voltage. This point is referred to as the "voltage

knee" as seen in Figure 2, at about 0.55 volts. Also note the variance in the voltage knee with temperature. As the cell temperature drops, its output voltage increases. You will get more output on a cold winter day than in the summer time!

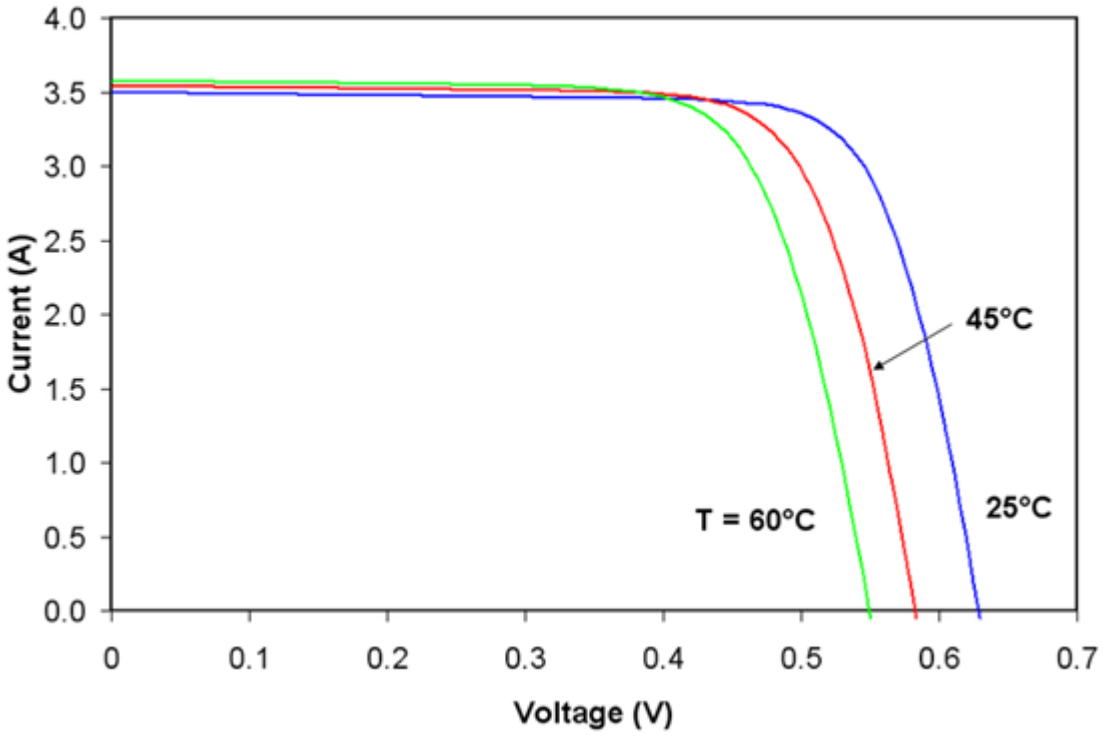

Figure 2: Solar Cell I-V Curve

Typical solar panel specifications:

Cell Type - Monocrystalline or ploycrystalline silicon.
Pmax - Maximum power output at STC.
Vmp - Voltage output at maximum power. This voltage, sometimes referred to as Vpp, is usually between 17 and 18 VDC for a 12 volt panel.
Voc - Voltage output at open circuit. This is the no-load output voltage and should be about 21 VDC for a 12 volt panel.
Imp - Current output at maximum power.
Isc - Short circuit current.
STC - Standard Test Conditions – Insolation at 1000 W/m^2 at 25 ºC
Maximum Efficiency – The efficiency should conform to the cell type previously discussed.
Maximum System Voltage – The capability of the panel to be series connected into larger arrays.
Number of cells – Number of cells connected in series to form an array. This number is 36 for a nominal 12 volt system or 72 for a nominal 24 volt system

Shading

If solar panels are wired in parallel, shading a part of an array will just reduce the power output. When solar panels are connected in series to produce higher voltage output, all the panels must carry the same current. If a panel in this series configuration stops producing current, the array will become reverse biased and dissipates power as heat. This heat can quickly destroy part or all of an expensive solar panel. The reverse bias situation can be prevented by using bypass diodes across each panel. The bypass diode (rated for the array's maximum output current) will carry the current around a module that is not contributing current.

Wind Load

Solar Panels can present a significant wind load so careful design of their mechanical support structure is required.

Solar Charge Controller

The Key Features of a Solar Charge Controller include:

- *Multistage charging of battery bank* – The controller must vary the amount of power sent to the batteries based on its charge level. This will prevent battery damage due to over or under charging.
- *Reverse current protection* – The controller must stop the solar panels from draining the batteries at night when there is no power coming from the solar panels.
- *Low voltage disconnect* – The controller should turn off the attached load when the battery is low and turns it back on when the battery is charged back up.
- *High efficiency* – the controller should maximize power transfer between solar array and battery.
- *Display*- the controller should show the voltage of battery bank, state of charge, amps coming in from solar panel.

Available Types of Controllers**:**

PWM (Pulse Width Modulation) solar charge controller - This type operates by making a connection directly from the solar array to the battery bank. During bulk charging, when there is a continuous connection from the array to the battery bank, the array output voltage is 'pulled down' to the battery voltage. As the battery charges, the voltage of the battery rises, so the voltage output of the solar panel rises as well, using more of the solar power as it charges. As a result, the nominal voltage of the solar array must match the voltage of the battery bank. The actual voltage of a 12V solar panel, when connected to a load, is close to 18 Vmp (Volts at maximum power). This is because a higher voltage source is required to charge a battery.

MPPT (Maximum Power Point Tracking) solar charge controller - This type will measure the Vmp voltage of the panel, and down-converts the PV voltage to the battery voltage. Because power into the charge controller equals power out of the charge controller, when the voltage is dropped to match the battery bank, the current is raised, maximizing the available power from the panel. A higher voltage, more readily available, solar array can be used to charge a low voltage battery bank. For example, using a 20V solar panel, a 12V battery bank can be charged. Using two panels in series will charge up to a 24V battery bank, and three in series can charge up to a 48V battery bank. This opens up wider range of solar panels that now can be used for a large off-grid solar system.

Storage Batteries

Batteries do not store electrical energy. They use chemical processes to produce electricity. These chemical processes are either Primary (one-shot), or Rechargeable. Further, these chemical processes are temperature, discharge current and cycle count dependent.
Rechargeable batteries include Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium-Ion (Li-Ion) and Lead-Acid. The energy density of these batteries and that of several liquid fuels is shown below:

- Diesel fuel - 12,700 Wh/Kg
- Gasoline - 12,200 Wh/Kg
- Li-Ion - 150 Wh/Kg
- NiMH - 100 Wh/Kg
- NiCd - 60 Wh/Kg
- Lead-Acid - 25 Wh/Kg

The Li-Ion, NiMH and NiCd batteries are typically too expensive for large amp-hour storage requirements, so this paper will discuss only the Lead-Acid battery. After seeing the difference in energy density between liquid fuels and batteries, it is pretty obvious why generators are such an effective electrical energy source!

Lead-Acid Batteries**:**

Lead-Acid batteries can be divided into two categories by discharge type as follows:

1. *SLI (Starter, Lighting and Ignition)* – This type of battery has high momentary current capability, but low continuous current and is limited to 20% of capacity discharge without permanent damage.
2. *Deep Cycle* – This battery is able to withstand discharges to 50% (SLA) or 80% (flooded cell) of capacity but typically cannot deliver engine "cranking" current. The newer SLA batteries are modifying this last characteristic.

Lead-Acid batteries are further divided by construction type as follows:

1. *Flooded-cell* - The plates of the battery are submerged in the liquid electrolyte.
2. *Sealed Lead-Acid (SLA) Batteries*:
    a. *Gel-cell* - A sealed lead-acid battery with a gelled electrolyte.
    b. *Absorbed Glass Mat (AGM)* – A sealed lead-acid battery with the electrolyte suspended in an absorbent glass mat next to the plates.

Specifications:
Cold Cranking Amps – The number of amperes the battery can deliver at 0ºF for 30 seconds and maintain a terminal voltage of 1.2 Volts per cell or 7.2 Volts for a 12 Volt battery. This is obviously an important specification for a SLI battery.
Reserve Capacity – The amount of time a battery at 80ºF can deliver 25 Amperes until the terminal voltage reaches 1.75 Volts per cell or 10.5 Volts for a 12 Volt battery.
Ampere Hours (C) – The storage capacity of a battery when discharged at its 20 hour rate until a terminal voltage of 10.5 volts is reached under load. Note that this capacity is a function of actual load current and temperature. The 20 hour rate is the specified ampere hour rating of the battery divided by twenty. For example, a 100 AH battery can deliver 5 amperes for 20 hours at 77ºF. A battery will have less capacity at higher discharge currents and lower temperatures and more capacity at lower discharge rates and higher temperatures.

Charging Lead-Acid Batteries:
Lead-Acid batteries can be quickly destroyed by overcharging or neglecting to promptly fully recharge after a deep discharge.
Overcharging: The SLA and Gel-cell batteries have very limited capacity to withstand an overcharge. During overcharging, the water portion of the electrolyte is converted (electrolyzed) to hydrogen and oxygen and

vented out of the battery. Since the trapped water cannot be replaced, as in a flooded cell battery, it is lost. Special design in the SLA battery allow a limited conversion of the electrolyzed hydrogen and oxygen back to water, but this process has limited capacity.
Undercharging: A lack of a complete recharge will allow the naturally formed sulfate crystals to harden on the lead plates, effectively killing that part of the battery.
Charging procedure:

1. Initially charge at a current equal to less than C/10 unless the manufacturer recommends a higher initial rate. If the battery is fully discharged, the required recharging AH's will be about 12% more than the battery capacity. For example, charge a 100 AH battery at 10 amps for 12 hours, i.e. 120 AH, or until the charge current drops to about 1 ampere.
2. Float the battery with a charge voltage of 13.2 to 13.65 Volts for at least 12 hours.

Best charging procedure is to use a multi-rate charger that will accomplish the process automatically. Most dual-rate chargers can provide a continuous float charge on the battery after charging is complete. Multi-rate chargers typically starts out constant-current and then switches to constant-voltage and then finally to a constant voltage float mode.

Discharging Lead-Acid Batteries:
A 12 Volt Lead-Acid battery will have an output voltage that starts at 12.6 volts and drops as it discharges to 10.6 volts when fully discharged at the C/20 rate. To prevent damaged to a SLA battery, it should be discharged only to 50% of its capacity or to an approximate terminal voltage of 12 volts under load at the C/20 rate. For example the Power Sonic 100 AH battery will indicate its 50% capacity after 10 hours of discharge at a current of 5 amperes and will have a terminal voltage of 12.0 Volts. Note that this voltage is only true at a temperature of 68º F with a C/20 load. The best way to care for a battery is to be aware of the discharge current and total time so as to not exceed the recommended 50% AH discharge. Then promptly recharge the battery fully and maintain it on a float charge.

Battery Booster:
A typical amateur radio transceiver is designed to supply full RF transmit power with a DC supply voltage of 13.8 VDC. At 12 Volts, the output power will be approximately 87 watts. The actual output may be even lower due to voltage drops in the battery system wiring. Several manufacturers have developed switch regulators, called power boosters, that takes the variable battery voltage and boosts it to a constant 13.8 volts. These boosters can supply from 25 Amperes (MFJ-4416B) to as much as 40 amperes (N8XJK Super Booster) from a DC sources as low as 9 Volts. They can be set to turn off at an adjustable input voltage to prevent excessive discharge and have a RF detector feature that only boosts the voltage during transmit. Further both of these product lines claim 90% conversion efficiency.

Battery Safety
No matter what kind of battery you are using they can be dangerous. All contain toxic materials and stored energy. Lead-Acid batteries demand the most respect. They are heavy, contain acid and can deliver very high currents that can start fires and produce serious burns. The old practice of removing your wedding ring when working around lead acid batteries is still a good rule. Documented stories tell of battery workers losing their ring finger when they accidentally got their wedding band across a Lead-Acid battery terminal pair.
A large fuse should be placed in the main current feed cable near the battery pack. The sports boating industry and Powerwerx, https://powerwerx.com/fuses-circuit-protection, have a nice selection of both high-current, DC, fuses and circuit breakers. Two examples can be seen in figure 3.

Circuit Breaker – Cooper/Bussmann – Series 285 Specifications:

- **Amperage:** 25A—150A (in 10 amp increments)
- **Voltage:** 240V AC, 65V DC
- **Mounting:** Surface
- **Circuit Breaker Type:** Thermally responsive Bi-metal blade
- **Terminal Studs:** M6 (accepts ¼" ring terminals)
- **Approvals**: CE, SAE J1171, IP67

Figure 3: DC fuse and Circuit Breakers

All Lead-Acid batteries give off some gas during charging and have the potential to produce large quantities of both hydrogen and oxygen, so all charging should be done in a ventilated space away from open flames.

Instrumentation

To sustain solar power operation, the energy in and out of the battery pack must be carefully measured and tracked to prevent eventually exhaustion of the battery pack. Fortunately, most solar charge controllers have displays or digital data streaming to monitor energy (voltage and current) in and out of the battery pack.

DESIGN EXAMPLE

A good way to illustrate the utilization of solar power for an Amateur/MARS HF station is to work through a design example. The jump kit station, used for this design example, is a typical, high performance, 100 watt digital station. It will be shown that even this type of station can be sustained on solar power with proper design and careful utilization of available solar power.
QRP equipment like the Yaesu FT-817, with a LDG-Z11ProII latching-relay auto-tuner and a tablet computer can significantly reduce station power consumption.

Design Goals

1. Sustainable operation of personal "jump kit" using only solar power and storage batteries.
2. Operate all modes (MIL-STD, Pactor, MT-63, SSB voice, VHF FM).
3. Occasional linear amplifier operation when propagation conditions are poor.
4. Occasional operation of a 1KW 60 Hz AC sinewave inverter for TV and other critical appliances.

A detailed block diagram of the "jump kit" can be found in Appendix A, Figure 4. The solar power system block diagram for the Epic PWRgate option is shown in Appendix B, Figure 5. Note that an Anderson power

pole jumper pair, mounted on the back panel of the jump kit, is used to connect the AC power supply and rig to the solar power battery system. When the jump kit is operated on AC power, a short jumper pair is installed in this connector pair. The Epic PWRGate is used to automatically select the battery charging source (solar panels or AC power supply). An alternate, cheaper, charge controller design, using the Renogy Rover 20A, is shown in Figure 6. This design does not have the automatic selection of the charging source.

Required Solar Power

The storage batteries provide the intermittent peak transmit current as well as sustaining operation when solar insolation is not available. Since the solar array can only supply power during the maximum insolation period, it must supply full operational power plus charge the batteries for night-time operation.

Personal Jump Kit power requirements:

Jump Kit (IC-7100, DR-7400, Signalink, four port USB Gearhead Hub) – 1.06 A receive mode
SG-235 auto-tuner – 0.65 A
Laptop (Panasonic CF-53) with Link CF-LNDDC 120 FA switching supply – 0.94 A
Receive power (total of above) – 2.65 A or 34.87 watts

Transmit (MS-DMT) –	11.7A
Transmit (MT-63) –	10.4 A
Transmit (Pactor – PSK) –	12.5 A
Transmit (Pactor – FSK) –	15.6 A
Transmit (CW tune) –	16.11A

Assuming a 10% transmit duty cycle in MS-DMT, the average power requirement is 44.7 watts (3.55 amperes at 12.6 volts DC). In 10 hours, a total of 35.5 AH or 447.3 Watt-Hours of energy will be consumed. The solar panel must supply this amount of total power (447.3 watts) in the available 5 hours (zone 3) of insolation or 89.46 watts per hour. Part of the energy will directly power the radio station and the remainder will be used to charge the battery pack for night-time operation. To achieve break-even operating, the operating hours have to be adjusted for available insolation. Tracking the sun by manually moving solar panels during the day can significantly increase available insolation time.

Selection of Solar Panel(s)

For this design, two of the panels shown in Appendix 3, figure 7, were purchased and connected in parallel or series depending on the MPPT controller under test. This resulted in output currents from 9 A to12 A. Test results for the two controllers are detailed below:

1. The Epic PWRgate controller typically provided charging currents of 9-10 A, resulting in power delivered to battery pack of 117 watts. Voltage drop in the 50 ft. #10 AWG solar array cable at 10A was 1 V. Solar panel output was 18.9 VDC so the MPPT controller could compensate for this 1 volt drop and still delivery maximum available current to the batteries with only a small reduction in efficiency. Measured efficiency at the controller, input to output, was 97%.
2. The Renogy Rover 20A controller typically provided charging currents of 12 A, resulting in power delivered to the batteries of 164 watts. Since the two panels were connected in series the voltage drop in the cable was 0.5 V. Solar panel output was 31.6V at 5.2A. Measured efficiency at the controller, input to output, was 97%.

Selection of Charge Controller

The West Mountain Radio Epic PWRGate, shown in Appendix 4, figure 8, was selected for initial testing due to its ability to interface with the jump kit. Its maximum capacity matches the maximum output current (10 A) of the selected solar panels connected in parallel, and had automatic selection of charge source. Also its maximum output current of 40A exceeds the station power requirement not including the linear amplifier.

The Renogy Rover 20A, shown in Appendix 4, figure 9, was also tested. This controller has a higher solar panel voltage and current rating and delivered 20% more charging current to the battery pack. The higher solar panel voltage of 100V allowed series connection of the solar panels, reducing losses in the power cable. Its only disadvantage is the absence of the "PWRgate" feature of charging from either the solar panels or an AC power supply.

Battery Storage Requirement

The storage battery pack for the above example are required to deliver an average of 3.55 A at 12.6 volts for 5 hours since the solar panel array will cover the remaining 5 hours. Storage battery requirements are therefore only 17.75 AH. Assuming a 50% discharge, the battery will need a total capacity of 35.5 AH at 12.6 VDC. This is easily realized with a single, 90 AH deep-cycle lead-acid battery as shown in Appendix 5, figure 10. To compensate for a significant number low-insolation days, three of these 90 AH batteries were connected in parallel, extend the battery only operation (10 hours per day) to 7.5 days. Power saving measured would have to be implemented to allow re-charge of the battery pack after this significant discharge period. The flooded cell, Lead-Acid battery type was selected to allow inspection and maintenance of the electrolyte level. Note that the flooded cell batteries are used in recreational vehicles and many of today's trucks (Ford F-250 for example).

Instrumentation

The West Mountain Radio PWRcheck, shown in Appendix 6, figure 11, was used to monitor the jump kit a energy into and out of the battery pack during testing of the EpicPWRgate option. The high discharge path, used for the linear amplifier and 1KW AC inverter, used the Powerwerx Watt Meter and Power Analyzer, shown in Appendix 6, figure 12. The PWRcheck consumes only 0.06 A and the Powerwerx meter is not turned on except during high discharge operations, so its consumption is insignificant.

The West Mountain Radio, RigRunner 4007U, shown in Appendix 6, figure 13, provided fused power distribution to all Jump Kit components, display of load current and voltage, and automatic load disconnect for over or under voltage conditions.

The PWRcheck meter is not needed for the Renogy Rover 20A option since the Rover displays both solar panel and battery charging parameters. The display of the Rigrunner 4007U is needed to monitor load current and voltage since the LOAD output of the Rover is not available due to a factory design overload flaw.

DC Power Connectors

Appendix 7, figure 14, shows the high power DC connectors and wire used in this project. Figure 15 shows the MC-4 solar panel connectors. Note the O-rings and packing glans on these connectors to make them weather resistant.

Results

It was decided to operate the station in receive-only mode for 12.8 hours per day to simulate the 10 hour, 10% transmit duty cycle load and to carefully monitor battery voltage. Sun tracking increased the available insolation by 60%, resulting in a calculated maximum receive operating time per day of 20.5 hours. Single battery operation confirmed that it might be possible to operate 24 hours per day in this receive only mode due to the ability of the solar panels and both controllers to exceed the required power delivery.

The following test result were obtained:

- Operated complete station in receive mode, without the linear amplifier, 24 hours per day for seven days on solar power using the Epic PWRgate controller. The Renogy Rover 20A was used for an additional two days during a proof of concept test.
- By tracking the sun, a 60% (8 hours versus 5 hours) increase in total solar power was realized per day. The panels were repositioned every two hours to point at the sun. The panel's sun shadow was used to adjust the tilt angle.

- Battery voltage was never lower than 12.4 VDC and the battery pack was fully charged at the end of the 7th day.
- One 90 AH battery was used for 1 of the 7 days of testing during the Epic PWRgate controller test period.
- Successfully operated the linear amp achieving 400 watts CW.
- Successfully operated 1KW AC sinewave inverter.
- Details of each controller's performance are shown below:
  - Renogy Rover 20A results:
    - Produced 20% more charging current than Epic PWRgate.
    - Load current must be drawn directly from battery due to a factory overload design flaw.
    - An external smart battery charger must be provided for AC power charging of battery pack unless only solar power will be used for charging.
    - A convenient LCD display allowed monitoring of solar panel and battery charging parameters.
    - An external load power meter (RigRunner 4007U) must be included to allow monitoring of load power.
    - Smart charging of the battery pack was observed that included Bulk, Boost, and Float charging modes.
  - Epic PWRgate results:
    - Smart charging of the battery pack was observed for both solar and AC power supply charging.
    - Firmware version 1.23 or greater must be installed for proper daily solar charging.
    - An external battery charging meter (PWRcheck) is needed to monitor battery charge/discharge state. The LED lights do not provide sufficient information.
  - Neither charge controller produced detectable switch noise at HF frequencies with the Jump kit next to battery pack.
- Recommend the use of a Battery Tender to maintain battery pack chemistry when the battery pack is not being charged by other means.

Construction Details

See Appendix 8.

Cost and Detailed Parts List

Appendix 9 provides a detailed cost breakdown for both the high current and low current versions using both the Epic PWRgate and Renogy Controllers. The low current option does not have the 75A wiring, 100A circuit breaker or Powerwerx wattmeter. To further reduce costs, the number of battery can be reduced from three to one, saving $200, but reducing the station ability to weather cloudy days.

APPENDIX 1 – JUMP KIT

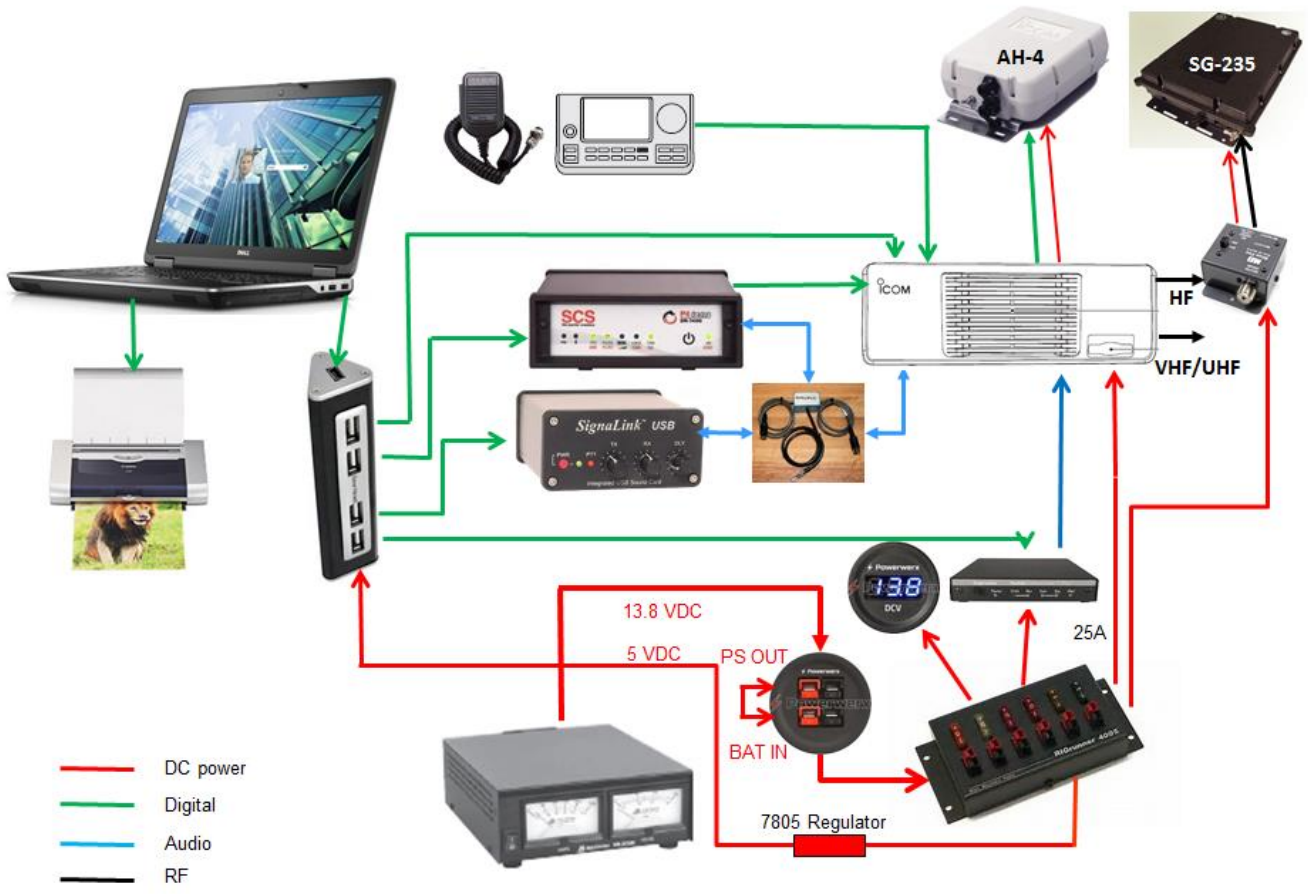

Figure 4: Jump Kit Block Diagram

APPENDIX 2: SOLAR POWER BLOCK DIAGRAMS

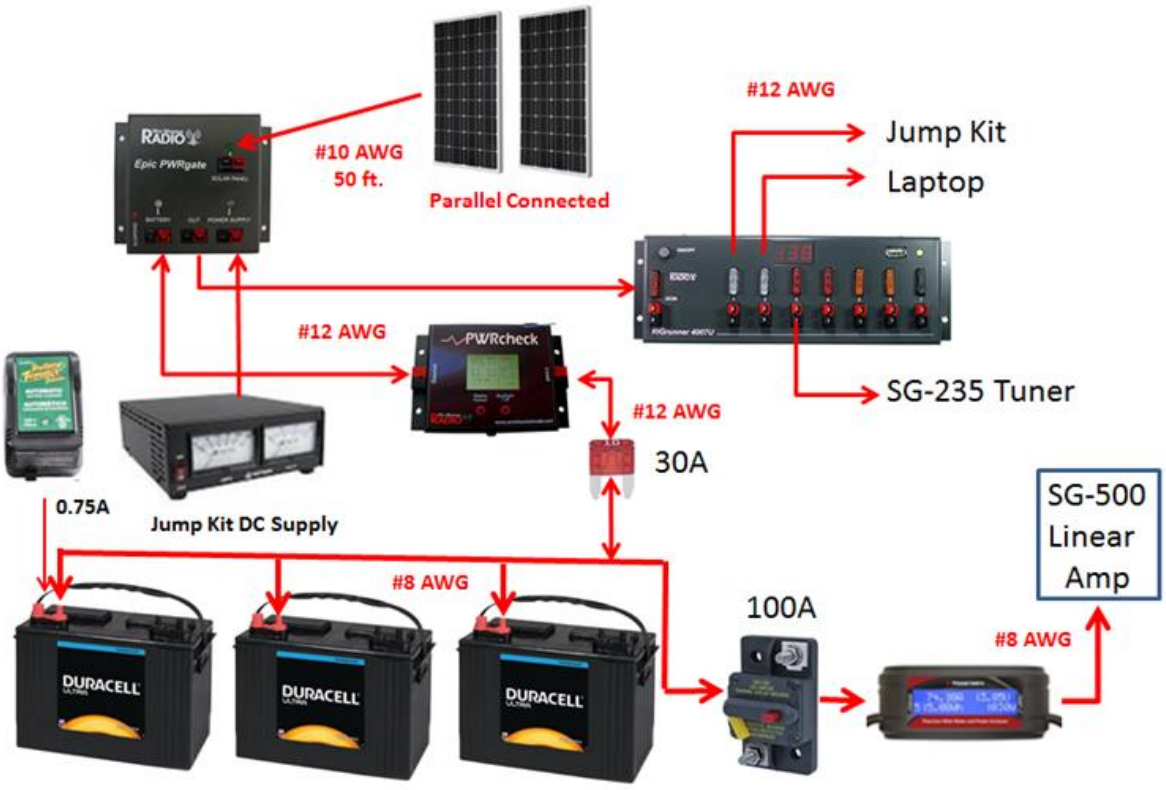

Figure 5: Solar Power Supply - Epic PWRgate Controller

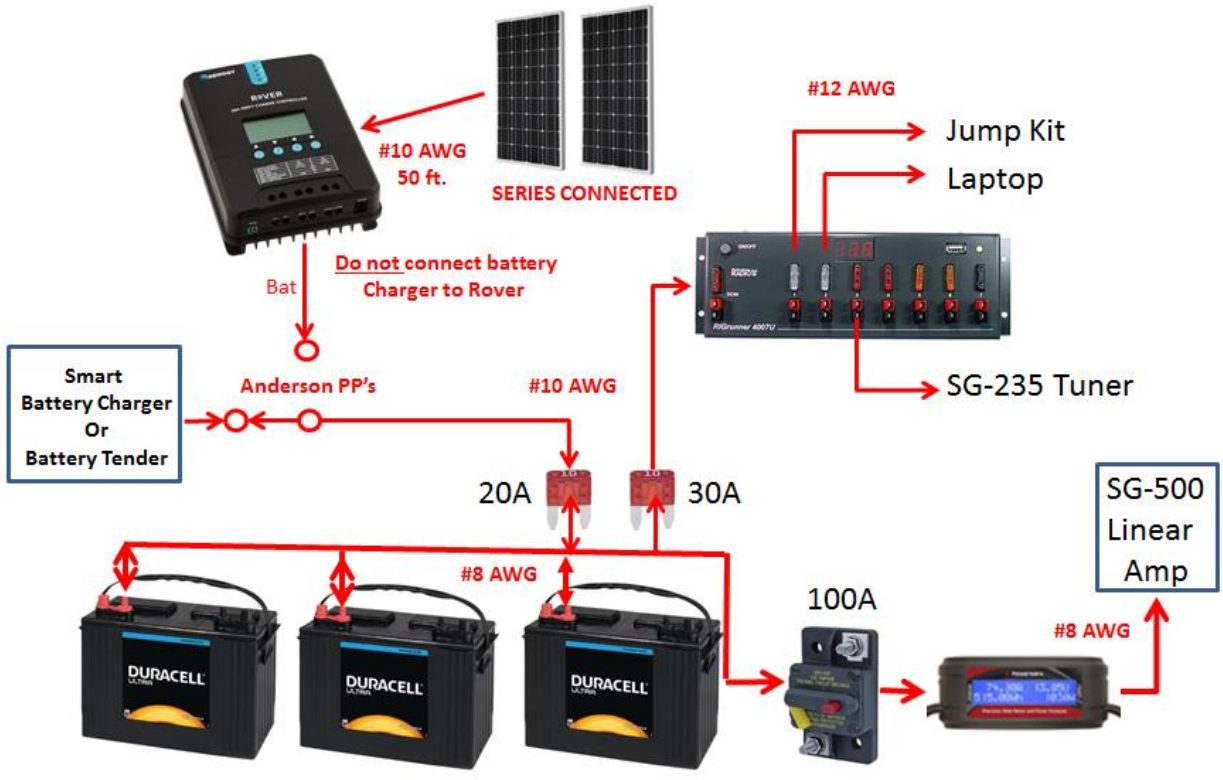

Figure 6 : Solar Power Supply – Renogy Rover 20A Controller

APPENDIX 3 – SOLAR PANELS

Efficiency is 21% - 22% (manufacturer's specification). Cost - $136.99/each plus shipping.

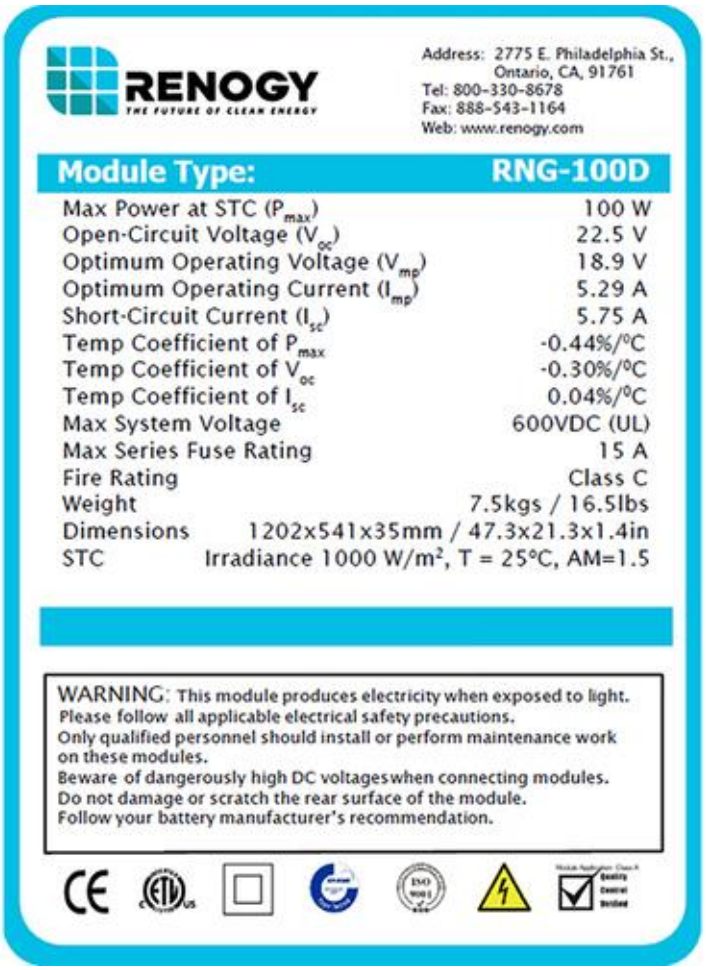
RENOGY
THE FUTURE OF CLEAN ENERGY
Address: 2775 E. Philadelphia St., Ontario, CA, 91761
Tel: 800-330-8678
Fax: 888-543-1164
Web: www.renogy.com
Module Type: RNG-100D
Max Power at STC (P_{max}) 100 W
Open-Circuit Voltage (V_{oc}) 22.5 V
Optimum Operating Voltage (V_{mp}) 18.9 V
Optimum Operating Current (I_{mp}) 5.29 A
Short-Circuit Current (I_{sc}) 5.75 A
Temp Coefficient of P_{max} -0.44%/°C
Temp Coefficient of V_{oc} -0.30%/°C
Temp Coefficient of I_{sc} 0.04%/°C
Max System Voltage 600VDC (UL)
Max Series Fuse Rating 15 A
Fire Rating Class C
Weight 7.5kgs / 16.5lbs
Dimensions 1202x541x35mm / 47.3x21.3x1.4in
STC Irradiance 1000 W/m², T = 25°C, AM=1.5
WARNING: This module produces electricity when exposed to light.
Please follow all applicable electrical safety precautions.
Only qualified personnel should install or perform maintenance work on these modules.
Beware of dangerously high DC voltages when connecting modules.
Do not damage or scratch the rear surface of the module.
Follow your battery manufacturer's recommendation.

Figure 7: Renogy 100 W Solar Panel

APPENDIX 4: SOLAR CHARGE CONTROLLERS

Figure 8: Epic PWRgate Charge Controller

Features of the Epic PWRgate Controller:

- Epic PWRgate is a 12 volt backup power system rated at 40 amperes continuous from either a Power Supply or a Battery.
- Connected equipment will instantly switch to battery during a power blackout or power supply failure.
- Low loss PWRgate provides forward voltage drop of only 0.05 volts.
- USB port access to monitor system or to change charge parameters.
- Program for specific battery types.
- Supports smart charging of either Lead Acid or Li-Ion battery charging up to 10A.
- Optional direct solar panel input for MPPT battery charging (all chemistries). Solar panel VOC must be <= 30V.
- Maximum Power Point Transfer (MPPT) charging provides the maximum power out of a solar panel.
- Can be programmed for vehicle use to suspend charging when the alternator is off.
- Complete LED status indicators.
- Battery charge suspend button to eliminate current draw or charger noise for 30 minutes. Possible RFI may be emitted from MPPT charge controller.
- Optional temperature probe to control charging based on battery temperature.
- Solid, durable construction in an aluminum case. Includes mounting holes for convenient and secure use in mobile units.
- Uses Anderson Powerpole® connectors.
- Cost - $179.95
- Source – West Mountain Radio

- Setting for Epic PWRgate controller:

- Set Jumpers to PB and 10 A.
- Must have firmware version 1.23 to prevent solar charger shut down after 24 hours.

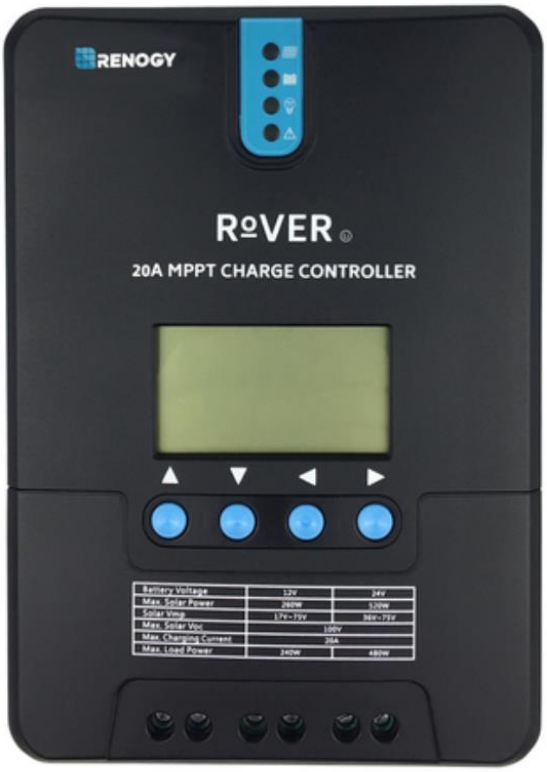

Figure 9: Renogy Rover 20A Charge Controller

Features of Renogy Rover 20A MPPT Charge Controller:

Automatically detects 12V/24V DC system voltages
High tacking efficiency of 99%
Peak Conversion efficiency of 98%
4-stage charging with MPPT output
Extensive electronic protections
Diverse load control
LCD screen with programmable charging parameters
Charging data with storage of up to 1 year
Die-cast aluminum design for heat dissipation

Specifications
Nominal system voltage: 12V/24V Auto Recognition
Rated Battery Current: 20A
Rated Load Current: 20A

Max. PV Input Short Current: 25A
Max. Battery Voltage: 32V
Max. Solar Input Voltage: 100 VDC
Discharge circuit voltage drop :≤ 0.15V
Mounting Oval: 0.30 x 0.18in
Net Weight: 3.08 lb.
Overall Dimension: 8.27 x 5.94 x 2.34in
Cost - $123.98 (Amazon)

Operational Use:

- This Charge Controller does not support battery charging from the jump kit power supply.
- An external "smart" battery charger must be connected to the battery pack for AC power charging. **Warning – the charge controller must be disconnected from the battery pack during AC charging. Use Anderson power pole pairs on the controller and battery charger, swapping connections. See Appendix 2, figure 6 , Renogy Rover 20A block diagram.**
- The two solar panels can be connected in series, reducing the solar panel cable loss.
- This controller has a LCD display that shows solar panel and battery charging parameters. If this controller is used, the PWRCheck meter is not needed.
- **The Rover 20A LOAD output could not be used due to an overload fault caused by the momentary charging of capacitors in the jump kit radio. The "factory" had no solution to this issue. Solar charging worked correctly, but DC power for jump kit operation had to come directly from the battery as shown in Appendix 2, figure 6. Use the Rigrunner 4007U display for load voltage and current.**
- During testing, the Renogy Rover 20A controller provided about 20% more charging current (12A versus 10 A) than the Epic PWRgate controller. The Renogy Rover 20A can provide up to 20A of charging current versus the 10A maximum for the Epic PWRgate. Further, the Rover has a maximum solar panel input voltage of 100V, allowing up to three of the selected solar panels to be connected in series.

APPENDIX 5 – STORAGE BATTERIES

Figure 10: Lead-Acid, Flooded, Storage Battery

Item Number: SLI27MDC

Brand: Duracell Ultra

Voltage: 12

Format: BCI Group 27M

Lead Acid Type: Deep Cycle

Cold Cranking Amps: 575

Battery Type: Basic

Capacity 20hr: 90AH

Chemistry: Lead Acid

Cranking Amps: 705

Lead Acid Design: Flooded

Made in the USA: True

Maintenance Free: No

Marine Cranking Amps: 705

Product Category: Marine/RV

Product Sub Category: Starting Lighting And Ignition

Terminal Type: DT, SAE/M8 Stud, SAE/M8 Threaded Post, WNT

Usage: RV, Sump Pump

Warranty: 12 Month Free Replacement

Weight: 53 lbs

Length: 12.5 in

Width: 6.75 in

Height: 9.375 in

Source – Batteries + Bulbs - $99.99/each
Sam's Club has better price

APPENDIX 6: INSTRUMENTATION

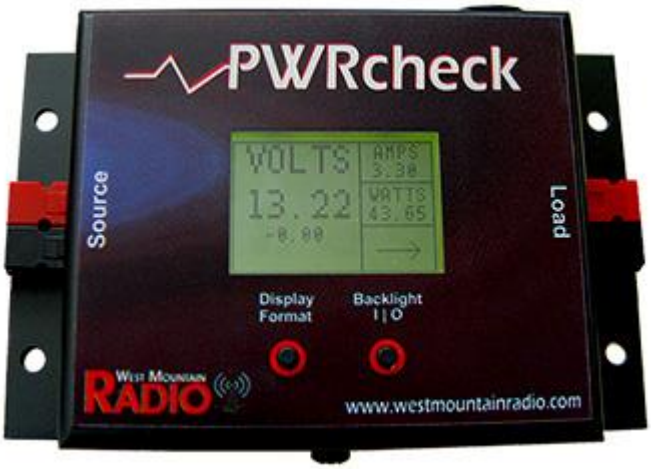

Figure 11: PWRcheck Meter

Capabilities

Hardware

- Handles 8 display modes including voltage, current flow in either direction, wattage and amp-hours
- Measures 0V* to 60V (Less than 8V requires USB power to PWRcheck), 40A continuous load
- Accurate to within +/- 10mV, +/- 10mA
- Resolution - 10mV, 10mA
- High side monitoring does not require breaking power supply ground or return path, ideal for vehicle use
- Backlit graphics LCD displays data in digital, analog and bar graph formats
- Monitor back up battery with programmable gas gauge
- Non-volatile memory stores more than 100,000 data points (nearly 2 1/2 month of data @ 1 point per minute) without power
- USB computer interface for configuration and data download
- Programmable alarm conditions for overcurrent, over/under voltage, amp-hours
- Uses Powerpole® connectors (see Accessories)
- Dimensions: 0.875" H x 4.5" W x 3" D

* PWRcheck requires a minimum 50mA load to measure voltages below 4.5V.

Software

- Easily program every aspect of PWRcheck operation such as data logging rate, display formats, alarm conditions
- Displays current, voltage, wattage and amp-hours in real time
- Integrated charting software automatically collects and displays data
- Downloads stored data for later analysis
- Exports to Excel

Computer System Requirements

Basic Requirements:

- At least an 800 X 600 graphics card and display monitor
- Windows XP, Vista®: 32 or 64 bit, Windows® 7: 32 or 64 bit, Windows® 8, Windows® 10
- An available USB port

Source - West Mountain Radio - $184.95

Figure 12: High Current Monitor

Specifications

- **Amps:** 75A continuous, 140A peak, 0.01 A resolution from 1 ~ 140
- **Voltage:** 0 ~ 60V, 0.01 V resolution (5 to 60V without optional auxiliary power connector)
- **Wire Type:** 8 gauge, high temperature wire (200°C)
- **Wire Length:** 4 inches on each side

- **Watts:** 0 ~ 7800W, 0.1 W resolution
- **Amp-hours:** 0 ~ 65Ah, 0.001 Ah resolution
- **Watt-hours:** 0 ~ 6554Wh, 0.1 Wh resolution
- **Display:** High-contrast blue backlit LCD display
- **Size:** 4.4 x 1.8 x 1.0" (111 x 45 x 26mm)
- **Weight:** 0.28 lbs. (126 g)
- **Warranty:** 1 Year Limited Warranty
- **Source – Powerwerx, Watmeter Plus 75A - $69.99**

Figure 13: RigRunner Power Distribution and Protection

Features

RIGrunner is the most convenient and safest way to connect all of your 12 volt equipment to a power source. It uses the excellent Anderson Powerpole® connectors, standardizing all of your 12VDC connections.

- 40 amp 12VDC continuous duty with 7 fused outlets.
- Automatic supply voltage and load current measurement shown on a 3 x 7 segment display.
- Pushbutton solid state on/off control.
- Built in PWRguard with automatic shut off on high (HVD) or low voltage condition (LVD) with audible alarm.
- Intelligent 2A USB port for charging iPhone, Android and other USB devices.
- Remote (wired) on/off and lockout capability included.
- Adjustable 7 segment display brightness.
- External input for use with electrical/mechanical interlocks.
- Internal RF bypass capacitors on all inputs and outputs.
- Source – West Mountain Radio – RigRunner 4007U – $169.95

APPENDIX 7: WIRE & CONNECTORS

DC Power Components - Powerwerx

PanelPole - $19.95

Anderson – 45A

Anderson – SB50

Red/Black Bonded Zip Cord
AWG #12, #10 & #8

Figure 14: DC Power Connectors and Wire

Solar Panel Connectors - Amazon

BougeRV 6PCS MC4 Solar Panel Cable Connectors 6 Pairs MC4 Male / Female - $7.99

MC4 Y-branch parallel Adapters - $8.95 Only needed for Epic PWRgate Version

Figure 15: Solar Panel Connectors

APPENDIX 8
Construction Details

The three 90 AH 12VDC batteries weight 156 lbs. so a substantial rolling carriage, using a Home Depo furniture dolly, was constructed as shown in Figure 16. This dolly is some 10 years old and has held a number of different types of lead-acid batteries without any failures. The wheels allow the battery pack to be moved from the ham shack to a well ventilated garage for high current charging.

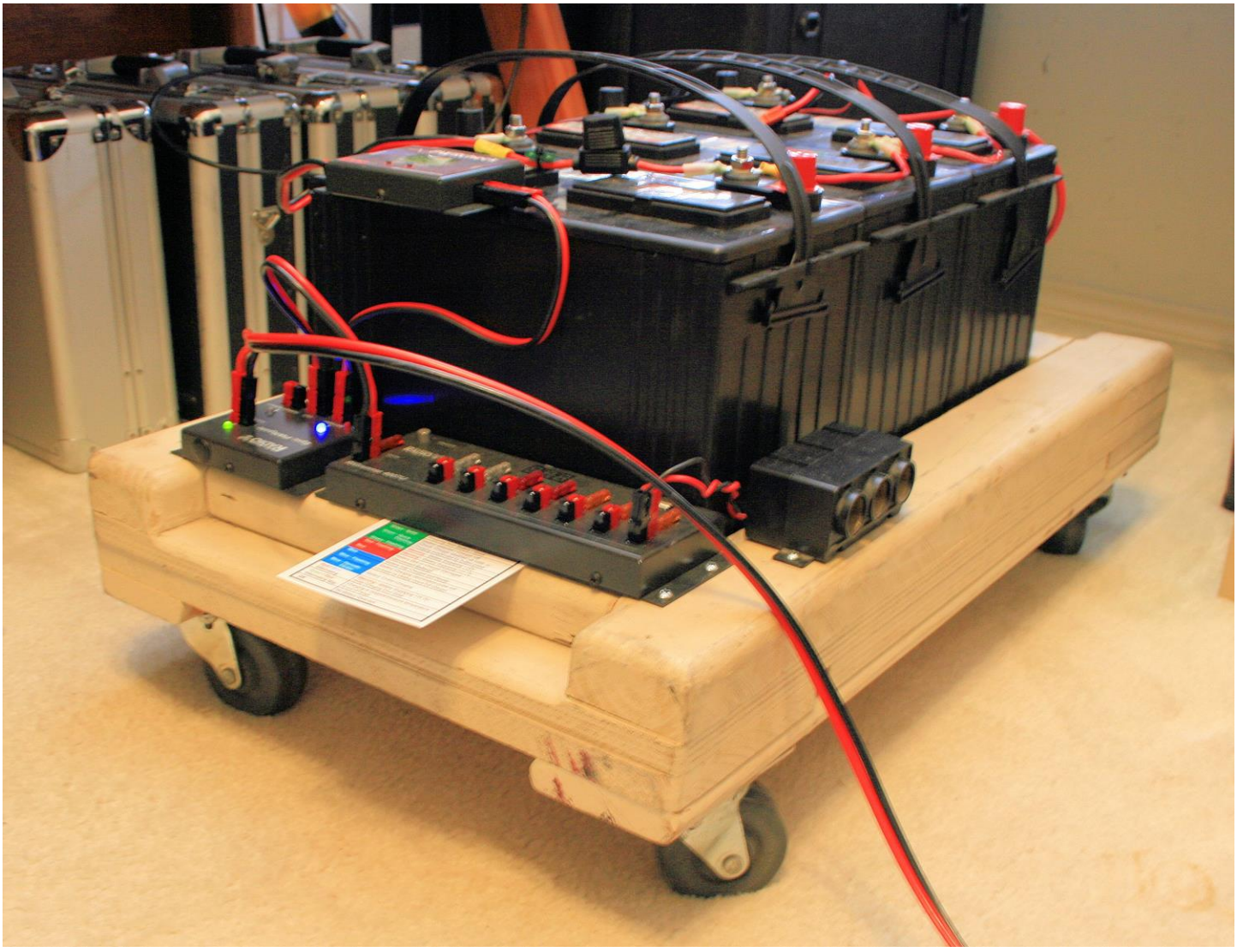

Figure 16: Battery Dolly

All the measurement and distribution components are mounted to the battery dolly frame with sheet metal screws. The PWRCheck meter was held to the battery with industrial grade two sided tape. The cigarette lighter power interface allows auto laptop switching power supply connection. All wiring on the facing side of the battery pack is AWG #12. The 30A ATO/ATC blade fuse can be seen upper center above the front battery. This fuse is one of two protective devices necessary to prevent a high-current fire hazard.
A top view of the battery pack can be seen in Figure 17. The high current battery circuit with the Powerwerx Watt meter and Anderson SB50 connectors can be seen in the lower portion of Figure 17. All parallel wiring on the batteries and high current circuits use AWG #8 wire. The AWG #12 pair existing to the left of Figure 17 provides an Anderson connection for a Battery Tender trickle charger. The Battery Tender has an ATO/ATC in line fuse (7.5 A).

Figure 17: Top View of Battery Pack

The 100A circuit breaker for the battery high current path can be seen in the Figure 18. This breaker is easily set and opened, so provided a convenient "power switch" for the high current path. The breaker was normally left in the open position to prevent unnecessary current drain by the Powerwerx wattmeter when no high current activity was occurring.

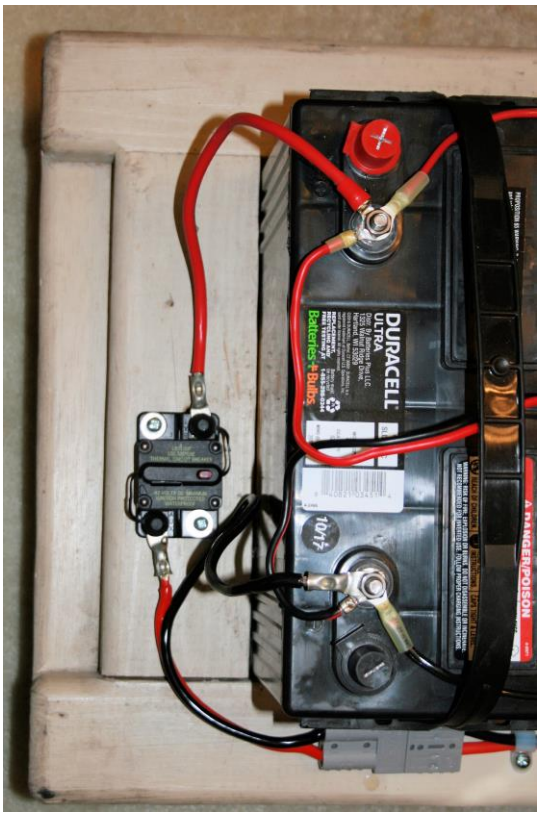

Figure 18: 100A Blue Sea Systems Circuit Breaker

The battery pack Epic PWRgate charging and low current discharge interface and instrumentation can be seen in Figure 19.

RigRunner - The RigRunner 4007U has a convenient master on/off push button. The display switches between input voltage and total current out. This provides a way to monitor radio/computer consumption while the PWRCheck meter shows total current into or out of the battery pack during charging or discharging activity (solar or AC supply).

PWRCheck - The PWRCheck displays an arrow in the lower right corner of the display reporting which way the current is moving (charging or discharging battery). The numeric display has a rich set of display options including voltage, current, watts and amp-hours. The amp-hour display is reset when source power to the PWRCheck meter is cycled. This allows monitoring total amp-hours in and out of the battery pack. Note that amp-hours meter does not run "backwards" during charging.

Epic PWRGate - The Epic PWRGate internal jumpers were set to **PB** and **10A** to accommodate a flooded cell Lead-acid battery pack. Use the WMR Device Diagnostic Utility found at:
http://www.westmountainradio.com/diagnostics
to verify that firmwave is version 1.23 or greater. This same utility can be used to update the firmware in the Epic PWRGate with firmware update found at : http://www.westmountainradio.com/content.php?page=wmr-downloads .

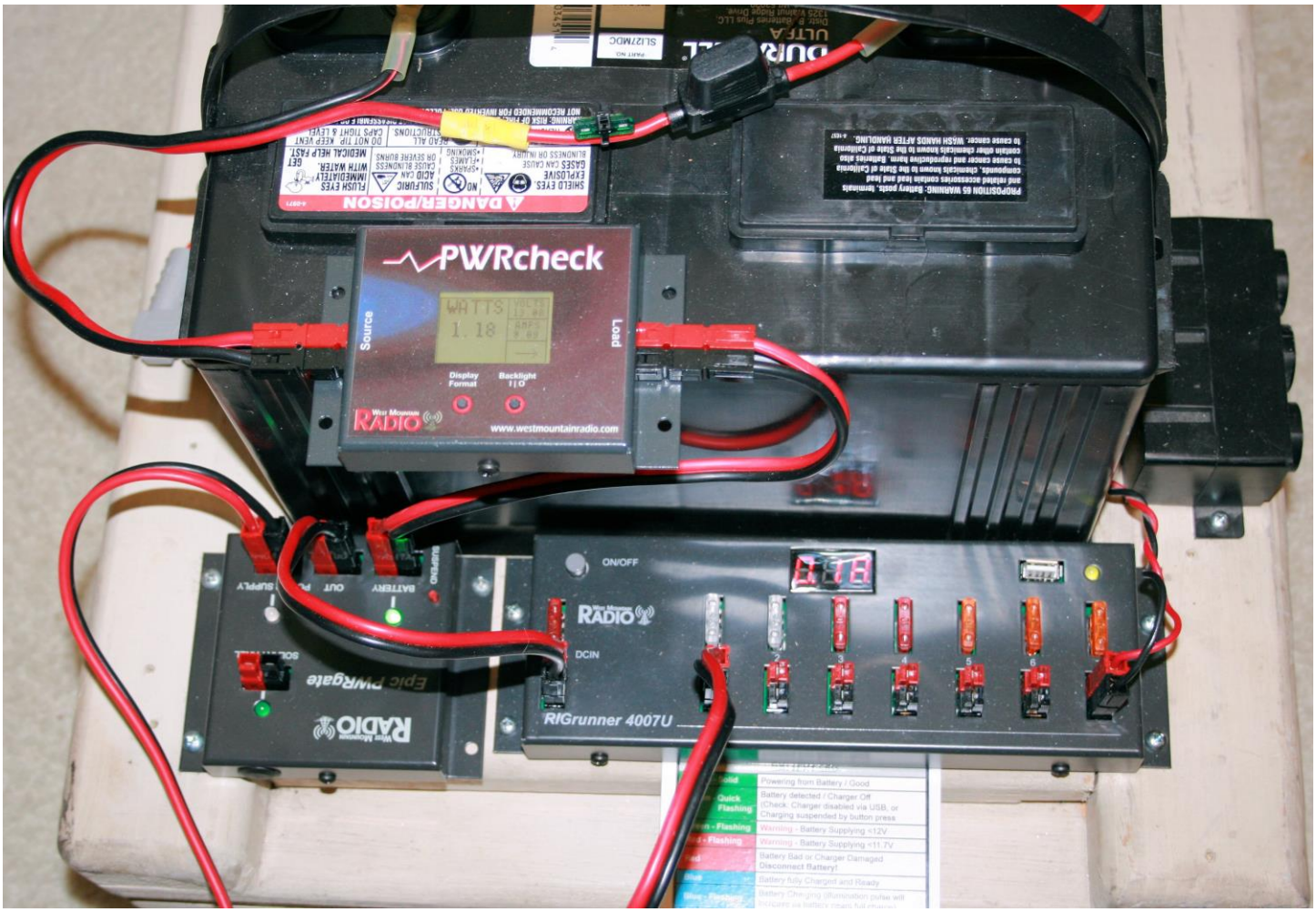

Figure 19: Epic PWRgate Instrumentation

The battery pack Renogy Rover 20A solar charging and low current discharge interface and can be seen in Figure 20. As previously discussed, the Rover 20A LOAD output cannot be used, due to its sensitivity to momentary short circuits like charging capacitors in amateur radio equipment. The Rover battery output connects to the battery pack through a 20A ATO/ATC fuse. Its display provide monitoring of solar panel output voltage and current, and battery charging voltage and current. The battery is connected through a 30A ATO/ATC fuse to the Rigrunner 4007U. The RigRunner display provides load voltage and current monitoring. Together these two devices provide complete monitoring of all power into and out of the battery pack. To trickle or smart battery charge from AC, the Anderson Power Pole connector on the battery output of the Rover 20A is disconnected and connected to the AC charger as shown in figure 6. The Rover is mounted to the battery frame using an Aluminum, expanded- metal angle bracket.

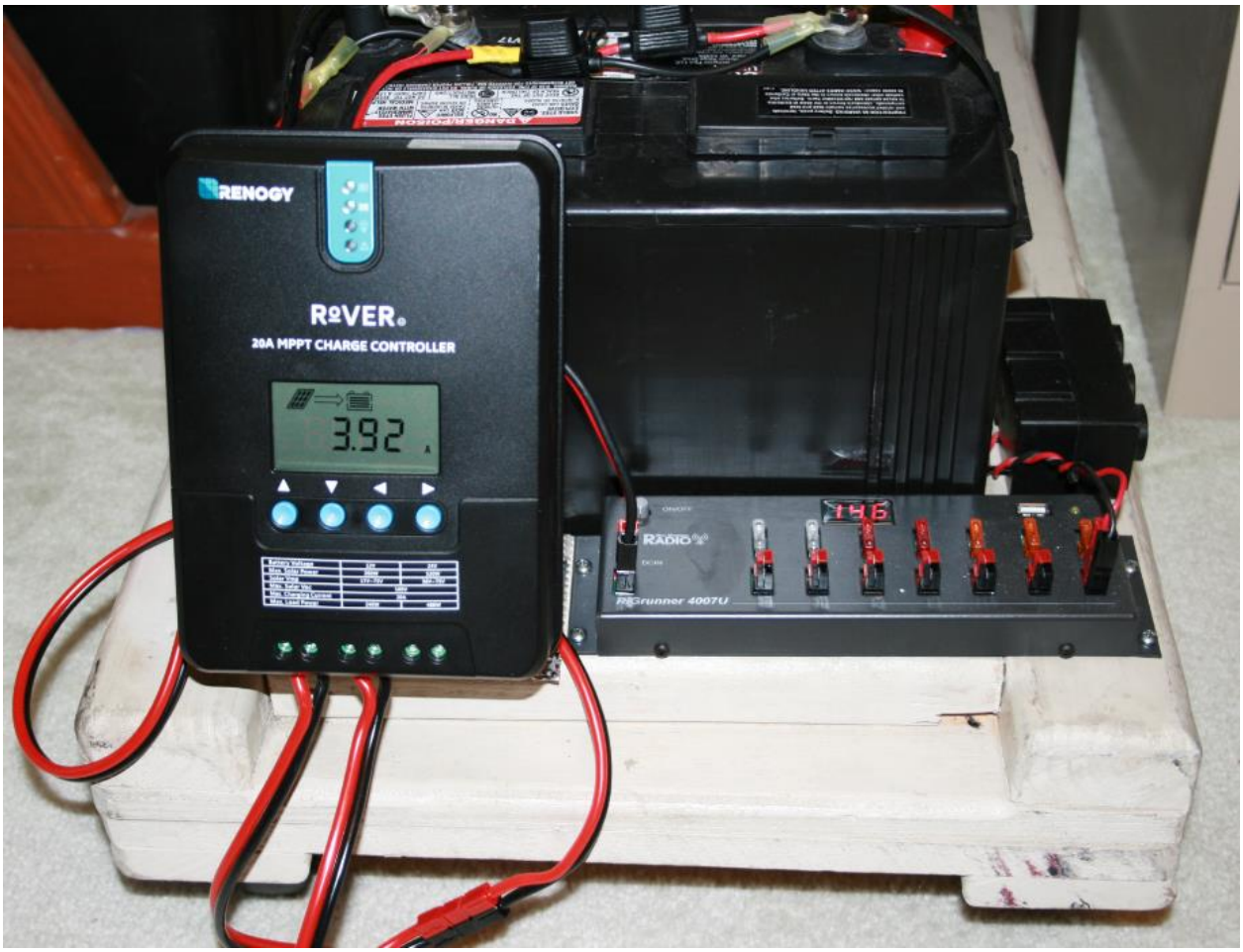

Figure 20: Renogy rover 20A Battery Pack Instrumentation

The back panel of the jump kit is shown in Figure 21. The Powerwerx panel meter, PanelPole, and the AC input can be seen on the left side of the panel. A short Anderson Power Pole jumper pair is used to connect PS OUT (Power Supply) to BAT IN (battery) to allow the rig to operate from the built-in AC power supply. These two supply interfaces can be connected to the Epic PWRgate controller to run the jump kit from the battery pack and to charge the battery pack from the jump kit AC power supply as shown in figures 4 and 5. Please contact me if you want further Jump Kit information.

Figure 21: Back panel of Jump Kit

Two high current devices that were operated from the battery pack are shown in Figure: 22. The SG-500 Linear Amplifier with its 5 ft. AWG#8 power cable produced 400 watts output with a 12.5 VDC battery pack. The maximum output power of 500 watts could not be realized due to voltage drops in the high current path (0.94V) and the reduced DC battery voltage. The SG-500 needs 13.8 VDC for maximum output power. Current in RTTY mode was measured at 52.3 amps at 11.4 VDC (SG-500 terminals) producing 400 watts output (Bird wattmeter). The AC inverter was not pushed to its limits during testing but performed correctly at reduced power draw. Note the use of Anderson SB50 connectors on both the SG-500 and 1KW inverter.

SG-500 Linear Amp.

SG-500 Power Cable

1KW AC Sinewave Inverter

Figure 22: High Current Devices

The Battery Tender Junior (750 mA) trickle charger and laptop switching power supply are shown in Figure 23. The battery tender is connected continuously during battery pack storage to prevent deterioation of the battery chemistry. The low current from this charger does not overcharge the battery or affect the electrolyte level.

Note: The electrolyte level in each cell should be checked periodically and refilled with distilled water before plate exposure.

Deltran Battery Tender Junior
Model 021-0123
Input – 120 VAC
Output - 12V at 750 mA

Laptop DC Supply
Link CF-LNDDC 120 FA

Figure 23: Battery Tender and Laptop DC Supply

Front and back views of the Solar Array can be seen in Figure 24. Door hinges were installed to allow the two panels to fold together for storage and protection. Frost King Self-Stick Rubber Foam (3/8" X 3/16") was applied aroung the edge of one panel to prevent damage when folded together. The MC4 Y-Branch connectors can be seen in the back view connecting the two panels electrically in parallel when using the Epic PWRgate controller. The gender of the connectors allow series connection for use with the Renogy Rover 20A without any additional connectors. For central Texas (30º Latitude), the panel angle needs to be adjustable from 3º (summer) to 50º (winter). To get maximum insolation, keep the panels at right angle to the sun's rays (using panel shadows).

Figure 24: Solar Panel Array – Front and Back Views

APPENDIX 9:

COST BREAKDOWN – Epic PWRgate With High Current Option

ITEM	Model	SOURCE	COST EACH	QUANTITY	TOTAL COST	COMMENTS
Solar Panel	Renogy RNG-100D	Amazon	$136.99	2	$273.98	Monocrystalline 100W, 12V
Solar Panel Y-connectors	BougeRV MC4 Y Branch	Amazon	$8.95	1	$8.95	both genders included
Solar Panel connectors	BougeRV MC4 6PCS	Amazon	$7.99	1	$7.99	need two pairs
Door hinge	3" 1/4RS SN	Home Depo	$2.58	2	$5.16	sold as pairs
Foam tape	Frost King 3/8 x 3 3/16	Home Depo	$3.96	2	$7.92	
Hingle hardware	SS - 6:32 bolts and nuts	Lowes		12		personal stock
Lead-Acid Storage Batteries	Duracell SL127MDC	Batteries+Bulbs	$99.99	3	$299.97	
Battery Ring Terminals	#6 1/4 in.	Lowes	$6.84	3	$20.52	Drill out to 5/16"
Furniture Dolly	Buffalo Tools - 1000 lbs.	Home Depo	$17.65	1	$17.65	
Plywood	3/4" model 106128	Home Depo	$39.98	1	$39.98	pressure treated, gnd. Contact
lumber - 2X4	2X4 model 106147	Home Depo	$3.88	1	$3.88	pressure treated, gnd. Contact
Solar Charge Contoller	Epic PWRgate	West Mountain Radio	$179.95	1	$179.95	
Power Monitor (low current)	PWRcheck	West Mountain Radio	$184.95	1	$184.95	40A maximum
Power Monitor (high current)	Wattmeter Plus 75A	Powerwerx	$69.99	1	$69.99	75A maximum
Power distribution panel	RigRunner 4007U	West Mountain Radio	$169.95	1	$169.95	
Battery Trickle Charger	Deltran model 021-0123	Batteries+Bulbs	$31.99	1	$31.99	0.75A maximum charge rate
In-line fuse holder ATC/ATO	IFH-10-02	Powerwerx	$2.59	1	$2.59	Low current battery output
100A Circuit breaker	Cooper CB285-100	Powerwerx	$27.99	1	$27.99	High current battery output
AWG#8 red/black zip cord	RM-08-25	Powerwerx	$49.03	1	$49.03	High current path, only need 10'
AWG#10 red/black zip cord	RM-10-50	Powerwerx	$63.06	1	$63.06	Solar Panel output run
AWG#12 red/black zip cord	RM-12-25	Powerwerx	$24.05	1	$24.05	All other interconnections
Anderson Power Pole 50A	SB50-08-GRY	Powerwerx	$3.15	5	$15.75	With contacts
Anderson Power Pole red	1327	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole black	1327G6	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole Contacts	261G2	Powerwerx	$0.36	24	$8.64	
Total					$1,522.82	

COST BREAKDOWN – Renogy Rover 20A With High Current Option

ITEM	Model	SOURCE	COST EACH	QUANTITY	TOTAL COST	COMMENTS
Solar Panel	Renogy RNG-100D	Amazon	$136.99	2	$273.98	Monocrystalline 100W, 12V
Solar Panel connectors	BougeRV MC4 6PCS	Amazon	$7.99	1	$7.99	need two pairs
Door hinge	3" 1/4RS SN	Home Depo	$2.58	2	$5.16	sold as pairs
Foam tape	Frost King 3/8 x 3 3/16	Home Depo	$3.96	2	$7.92	
Hingle hardware	SS - 6:32 bolts and nuts	Lowes		12		personal stock
Lead-Acid Storage Batteries	Duracell SL127MDC	Batteries+Bulbs	$99.99	3	$299.97	
Battery Ring Terminals	#6 1/4 in.	Lowes	$6.84	3	$20.52	Drill out to 5/16"
Furniture Dolly	Buffalo Tools - 1000 lbs.	Home Depo	$17.65	1	$17.65	
Plywood	3/4" model 106128	Home Depo	$39.98	1	$39.98	pressure treated, gnd. Contact
lumber - 2X4	2X4 model 106147	Home Depo	$3.88	1	$3.88	pressure treated, gnd. Contact
Solar Charge Contoller	Renogy Rover 20A	Amazon	$123.98	1	$123.98	
Power Monitor (high current)	Wattmeter Plus 75A	Powerwerx	$69.99	1	$69.99	75A maximum
Power distribution panel	RigRunner 4007U	West Mountain Radio	$169.95	1	$169.95	
Battery Trickle Charger	Deltran model 021-0123	Batteries+Bulbs	$31.99	1	$31.99	0.75A maximum charge rate
In-line fuse holder ATC/ATO	IFH-10-02	Powerwerx	$2.59	1	$2.59	Low current battery output
100A Circuit breaker	Cooper CB285-100	Powerwerx	$27.99	1	$27.99	High current battery output
AWG#8 red/black zip cord	RM-08-25	Powerwerx	$49.03	1	$49.03	High current path, only need 10'
AWG#10 red/black zip cord	RM-10-50	Powerwerx	$63.06	1	$63.06	Solar Panel output run
AWG#12 red/black zip cord	RM-12-25	Powerwerx	$24.05	1	$24.05	All other interconnections
Anderson Power Pole 50A	SB50-08-GRY	Powerwerx	$3.15	5	$15.75	With contacts
Anderson Power Pole red	1327	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole black	1327G6	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole Contacts	261G2	Powerwerx	$0.36	24	$8.64	
Total					$1,272.95	

COST BREAKDOWN – Epic PWRgate Without High Current Option

ITEM	Model	SOURCE	COST EACH	QUANTITY	TOTAL COST	COMMENTS
Solar Panel	Renogy RNG-100D	Amazon	$136.99	2	$273.98	Monocrystalline 100W, 12V
Solar Panel Y-connectors	BougeRV MC4 Y Branch	Amazon	$8.95	1	$8.95	both genders included
Solar Panel Y-connectors	BougeRV MC4 6PCS	Amazon	$7.99	1	$7.99	need two pairs
Door hinge	3" 1/4RS SN	Home Depo	$2.58	2	$5.16	sold as pairs
Foam tape	Frost King 3/8 x 3 3/16	Home Depo	$3.96	2	$7.92	
Hingle hardware	SS - 6:32 bolts and nuts	Lowes		12		personal stock
Lead-Acid Storage Batteries	Duracell SL127MDC	Batteries+Bulbs	$99.99	3	$299.97	
Battery Ring Terminals	#6 1/4 in.	Lowes	$6.84	3	$20.52	Drill out to 5/16"
Furniture Dolly	Buffalo Tools - 1000 lbs.	Home Depo	$17.65	1	$17.65	
Plywood	3/4" model 106128	Home Depo	$39.98	1	$39.98	pressure treated, gnd. Contact
lumber - 2X4	2X4 model 106147	Home Depo	$3.88	1	$3.88	pressure treated, gnd. Contact
Solar Charge Contoller	Epic PWRgate	West Mountain Radio	$179.95	1	$179.95	
Power Monitor (low current)	PWRcheck	West Mountain Radio	$184.95	1	$184.95	40A maximum
Power distribution panel	RigRunner 4007U	West Mountain Radio	$169.95	1	$169.95	
Battery Trickle Charger	Deltran model 021-0123	Batteries+Bulbs	$31.99	1	$31.99	0.75A maximum charge rate
In-line fuse holder ATC/ATO	IFH-10-02	Powerwerx	$2.59	1	$2.59	Low current battery output
AWG#10 red/black zip cord	RM-10-50	Powerwerx	$63.06	1	$63.06	Solar Panel output run
AWG#12 red/black zip cord	RM-12-25	Powerwerx	$24.05	1	$24.05	All other interconnections
Anderson Power Pole red	1327	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole black	1327G6	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole Contacts	261G2	Powerwerx	$0.36	24	$8.64	
Total					$1,360.06	

COST BREAKDOWN – Renogy Rover 20A Without High Current Option

ITEM	Model	SOURCE	COST EACH	QUANTITY	TOTAL COST	COMMENTS
Solar Panel	Renogy RNG-100D	Amazon	$136.99	2	$273.98	Monocrystalline 100W, 12V
Solar Panel connectors	BougeRV MC4 6PCS	Amazon	$7.99	1	$7.99	need two pairs
Door hinge	3" 1/4RS SN	Home Depo	$2.58	2	$5.16	sold as pairs
Foam tape	Frost King 3/8 x 3 3/16	Home Depo	$3.96	2	$7.92	
Hingle hardware	SS - 6:32 bolts and nuts	Lowes		12		personal stock
Lead-Acid Storage Batteries	Duracell SL127MDC	Batteries+Bulbs	$99.99	3	$299.97	
Battery Ring Terminals	#6 1/4 in.	Lowes	$6.84	3	$20.52	Drill out to 5/16"
Furniture Dolly	Buffalo Tools - 1000 lbs.	Home Depo	$17.65	1	$17.65	
Plywood	3/4" model 106128	Home Depo	$39.98	1	$39.98	pressure treated, gnd. Contact
lumber - 2X4	2X4 model 106147	Home Depo	$3.88	1	$3.88	pressure treated, gnd. Contact
Solar Charge Contoller	Renogy Rover 20A	Amazon	$123.98	1	$123.98	
Power distribution panel	RigRunner 4007U	West Mountain Radio	$169.95	1	$169.95	
Battery Trickle Charger	Deltran model 021-0123	Batteries+Bulbs	$31.99	1	$31.99	0.75A maximum charge rate
In-line fuse holder ATC/ATO	IFH-10-02	Powerwerx	$2.59	1	$2.59	Low current battery output
AWG#10 red/black zip cord	RM-10-50	Powerwerx	$63.06	1	$63.06	Solar Panel output run
AWG#12 red/black zip cord	RM-12-25	Powerwerx	$24.05	1	$24.05	All other interconnections
Anderson Power Pole red	1327	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole black	1327G6	Powerwerx	$0.37	12	$4.44	
Anderson Power Pole Contacts	261G2	Powerwerx	$0.36	24	$8.64	
Total					$1,110.19	